Fuel Cell Technologies Program Record	
Record #: 12012	**Date:** March 2, 2012
Title: Fuel Cell Bus Targets	
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Item:

Performance, cost, and durability targets for fuel cell transit buses are presented in Table 1. These market-driven targets represent technical requirements needed to compete with alternative technologies. They do not represent expectations for the status of the technology in future years.

Table 1. Performance, cost, and durability targets for fuel cell transit buses.

	Units	2012 Status	2016 Target	Ultimate Target
Bus Lifetime	years/miles	5/100,000[1]	12/500,000	12/500,000
Power Plant Lifetime[2,3]	hours	12,000	18,000	25,000
Bus Availability	%	60	85	90
Fuel Fills[4]	per day	1	1 (< 10 min)	1 (< 10 min)
Bus Cost	$	2,000,000	1,000,000[5]	600,000[5]
Power Plant Cost[2]	$	700,000	450,000[5]	200,000[5]
Hydrogen Storage Cost	$	100,000	75,000	50,000
Road Call Frequency (Bus/Fuel Cell System)	miles between road calls	2,500/10,000	3,500/15,000	4,000/20,000
Operation Time	hours per day/days per week	19/7	20/7	20/7
Scheduled and Unscheduled Maintenance Cost[6]	$/mile	1.20	0.75	0.40
Range	miles	270	300	300
Fuel Economy	miles per gallon diesel equivalent	7	8	8

[1] Status represents data from NREL fuel cell bus evaluations. New buses are currently projected to have 8 year / 300,000 mile lifetime.
[2] The power plant is defined as the fuel cell system and the battery system. The fuel cell system includes supporting subsystems such as the air, fuel, coolant, and control subsystems. Power electronics, electric drive, and hydrogen storage tanks are excluded.
[3] According to an appropriate duty cycle.
[4] Multiple sequential fuel fills should be possible without increase in fill time.
[5] Cost targets represent acquisition cost projected to a production volume of 400 systems per year. This production volume is assumed for analysis purposes only, and does not represent an anticipated level of sales.
[6] Excludes mid-life overhaul of power plant.

* The data, assumptions, and targets were reviewed by DOT (Christina Gikakis, Sean Ricketson, Gregory Rymarz) and NREL (Leslie Eudy).

Supporting Information:

On May 9, 2011, the U.S. Departments of Energy (DOE) and Transportation (DOT) issued a joint request for information (RFI), DE-FOA-0000542 [1], soliciting comments from stakeholders and the research community on proposed technical targets for fuel cell transit buses. The targets proposed in the RFI, as detailed in Table 2, were generated at a pre-RFI workshop organized by DOE and DOT on June 7, 2010 in Washington, D.C. [2], and were further revised through interactions with the research community prior to release of the RFI.

Table 2. Performance, durability, and cost targets for fuel cell transit buses proposed in the 2010 RFI.

	Units	Current Status (Estimated)	Commercialization Target
Bus Lifetime	years/hours	TBD	12/36,000
Power Plant Lifetime[1]	years/hours	NA/8,000	6/18,000
Bus Availability	%	66	85
Fuel Fills[2]	per day	1	1 (< 10 min)
Bus Cost	$	2,300,000	1,000,000
Power Plant Cost[3]	$	TBD	TBD
Road Call Frequency (All/Powerplant)	miles between road calls	1,900/2,400	4,000/10,000
Operation Time	hours per day/days per week	19/7	20/7
Operating Cost	$/mile (includes fuel)	TBD	1.16
Range	Miles	>300	300
Efficiency	%	TBD	TBD

[1] According to an appropriate duty cycle
[2] Time to fill is important (should be less than 10 min)
[3] Includes cost of fuel cell system and battery system. Excludes power electronics.

Stakeholders and researchers submitted recommendations to DOE in response to the RFI. Revisions to the proposed targets were made using information provided in the RFI responses, as well as information obtained in subsequent discussions with respondents, and through peer reviews provided by several stakeholders and independent experts. The revisions are documented below. In addition to revising the ultimate targets, interim targets were established for 2016. These targets are intended to represent values required for initial commercialization.

Bus Lifetime

RFI respondents indicated that the proposed 36,000 hour target was too low, and that a target expressed in terms of mileage would be more appropriate than a target expressed in hours. Therefore, the bus lifetime ultimate target was changed from 12 years / 36,000 hours to 12 years / 500,000 miles. The targeted 500,000 mile lifetime is roughly equivalent to 50,000 hours at typical average bus operating speeds. The 12 year/500,000 mile lifetime target is based on DOT minimum service life specifications, which require transit authorities to operate heavy-duty transit buses for a minimum of 12 years or 500,000 miles. Attainment of the minimum specified service life by the 2016 time frame is required for initial competitiveness with alternative technologies. Therefore, the 2016 interim target is identical to the ultimate target. The current status of 5 years and 100,000 miles represents data from the NREL fuel cell bus evaluations [3].

Power Plant Lifetime

The definition of "power plant" was clarified to include all components of the fuel cell system, including air, fuel, coolant, and control subsystems, as well as the battery system, and to exclude power electronics and the electric drive system. The inclusion of batteries in the power plant definition is required to provide a balanced comparison of systems with varying degrees of hybridization.

While the on-road bus lifetime target was revised to be expressed in terms of mileage, the power plant lifetime remains defined in terms of hours; a metric in terms of hours was deemed more appropriate for laboratory testing of fuel cell bus power plants. The power plant lifetime status was changed from 8,000 hours to 12,000 hours, based on RFI input and subsequent stakeholder input on demonstrated lifetime and warranties offered. This may include a planned stack replacement and/or battery replacement that is part of the baseline cost of the power plant. The power plant lifetime ultimate target was increased from 6 years / 18,000 hours to 25,000 hours, a change necessary to keep the power plant lifetime target equal to 50% of the bus lifetime target, with an interim target of 18,000 hours in 2016. The number of years is not specified in the new metric, based on stakeholder input indicating that durability in hours is the relevant metric. The 50% relationship between the power plant lifetime and bus lifetime ultimate targets is based on the expectation that the power plant will be overhauled, and the fuel cell stack and/or battery pack replaced, at the midpoint of the bus lifetime. This overhaul would be analogous to the mid-life overhaul typically performed on diesel bus engines.

Bus Availability

The bus availability status was decreased from the proposed value of 66% to 60%, based on data from the NREL fuel cell bus evaluations. Problems with the fuel cell system account for only a small fraction of the unavailable days. Approximately 90% of the unavailable days are attributed primarily to problems in other bus subsystems, including the battery pack, hybrid electric drive, and general bus maintenance. The bus availability ultimate target was increased from 85% to 90%, a value indicated by RFI responses to be achievable, and one that could provide a competitive advantage over conventional diesel ICE buses (availability around 85%). An interim target of 85% in 2016 was established.

Fuel Fills

A fuel cell transit bus would be expected to refuel once per day. Based on RFI input and subsequent discussion with stakeholders, the targeted time required for filling was maintained at less than 10 minutes. While shorter filling times could improve the competitiveness of fuel cell buses, this marginal improvement in competitiveness is not expected to justify the R&D cost required to develop fast fill technology, and the expected increase in cost when using this technology.

Bus Cost

The bus cost status was decreased from $2.3M to $2M based on RFI input. RFI respondents indicated that an appropriate bus cost target would be between $700K and $1M, but based on a lifecycle cost analysis, a more aggressive target was selected. At the targeted fuel economy level of 8 miles per gallon diesel equivalent (mpgde), and an assumed hydrogen cost of $4 per gge ($4.55 per gde), a fuel cell bus would be expected to yield lifetime (over 12 years) fuel savings worth nearly $300K when compared with a conventional diesel bus operating at 4 mpg [4] and an assumed diesel cost of $4.50 per gallon [5]. Therefore, with the assumption that a fuel cell bus could be competitive at a cost approximately $300K higher than a conventional diesel bus, a cost target of $600K was selected. However, achievement of even lower cost levels may be required to reach lifecycle cost parity with conventional diesel buses, given that fuel cell buses would have higher power plant overhaul costs. The $600K target is deemed appropriate at present, as it would represent a 70% decrease from current cost status, but the target should be reexamined in future years to address expected changes in operating costs, maintenance costs, and energy prices. Recognizing that achievement of this target is not expected in the near term, an interim target of $1M in 2016 was established. These targets are intended to be achieved at an annual production volume of 400 buses per year, which represents approximately 10% of the annual U.S. transit bus market of 4,000 buses per year [6]. This production volume is specified for analysis purposes only, and does not represent an anticipated level of sales.

Power Plant Cost

The current average power plant cost status has been determined to be approximately $700K, based on RFI responses and subsequent discussion with stakeholders. For a typical fuel cell system of around 150 kW, this status equates to $4,700/kW.

The power plant cost target of $200K was based on RFI input on appropriate cost apportionment for bus subsystems. Based on assumptions of a total bus cost of $600K, a cost premium of approximately $300K for a fuel cell bus over a conventional diesel bus, and $50K in savings due to elimination of the diesel engine and associated diesel subsystems, the allowable cost of the remaining subsystems (the power plant, hydrogen storage system, and electric drive) would be approximately $600K - $300K + $50K = $350K. Of this total, $200K has been apportioned to the power plant.

Similar to the case of the total bus cost target, the power plant target is lower (by approximately $100K) than most suggestions from the RFI. However, achievement of this aggressive target is desired to allow fuel cell buses to be economically competitive with diesel buses in the absence of tax credits and other favorable policy provisions. Recognizing that significant R&D will be required to achieve the ultimate cost target, an interim target of $450K in 2016 was established.

Hydrogen Storage Cost

The targets were clarified to indicate that the hydrogen storage system is treated separately from the power plant. Based on RFI input and subsequent peer review by stakeholders, an ultimate cost target of $50K and a 2016 interim target of $75K were established for the hydrogen storage system, with a current status of $100,000. For a typical onboard capacity of around 40 kg, this status equates to $75/kWh.

Road Call Frequency

The road call frequency target for the power plant was redefined as a target for the fuel cell system, which was deemed a more relevant metric for fuel cell buses. The status was updated based on more recent data from the NREL fuel cell bus evaluations [3], and the target was adjusted as required due to the change from a power plant target to a fuel cell system target.

Scheduled and Unscheduled Maintenance

As defined in the RFI, "operating cost" includes the cost of fuel; however, the introduction of a fuel economy target makes the inclusion of fuel cost in the operating cost target superfluous. Therefore, "operating cost" has been replaced with "scheduled and unscheduled maintenance cost." The status according to the new definition is $1.20/mile, based on an average of data from the NREL fuel cell bus evaluations [3], while the interim and ultimate targets are $0.75/mile and $0.40/mile, respectively, based on RFI responses and subsequent peer review by stakeholders.

Range

RFI responses indicated that the proposed vehicle range target of 300 miles is appropriate. The range status was decreased to 270 miles, based on data from the NREL fuel cell bus evaluations [3].

Efficiency / Fuel Economy

Since the fuel cell bus targets are mostly system-level targets, a fuel economy target was determined to be more appropriate than the proposed efficiency target. Based on RFI responses and data from the NREL fuel cell bus evaluations [3], fuel economy status was determined to be 7 mpgde. The new target, 8 mpgde, is slightly higher than targets suggested in the RFI responses, but this more aggressive target was determined to be appropriate, based on the already high status, and the need to decrease lifecycle cost.

References

[1] Fuel Cell Transit Bus Targets. DE-FOA-0000542. https://www.fedconnect.net/FedConnect/PublicPages/PublicSearch/Public_Opportunities.aspx?doc=DE-FOA-0000542&agency=DOE

[2] DOE/DOT Joint Fuel Cell Bus Workshop, June 7, 2010, Washington, D.C. http://www1.eere.energy.gov/hydrogenandfuelcells/wkshp_fcbus10.html

[3] NREL Hydrogen Fuel Cell Bus Evaluations, http://www.nrel.gov/hydrogen/proj_fc_bus_eval.html

[4] Leslie Eudy, "Technology Validation: Fuel Cell Bus Evaluations," 2012 Annual Merit Review, http://www.hydrogen.energy.gov/pdfs/review12/tv008_eudy_2012_o.pdf

[5] 2020 Reference Case, Annual Energy Outlook 2012, DOE/EIA-0383(2012), http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf

[6] New buses delivered annually, averaged from 2006-2010. American Public Transportation Association 2012 Public Transportation Fact Book, Appendix A Historical Tables, page 25, http://www.apta.com/resources/statistics/Documents/FactBook/2012-Fact-Book-Appendix-A.pdf